Q16.

Glucose can decompose in the presence of microorganisms to form a range of products. One of these is a carboxylic acid (M_r = 88.0) containing 40.9% carbon and 4.5% hydrogen by mass.

(a) Deduce the empirical and molecular formulas of the carboxylic acid formed.

Empirical formula = _____ Molecular formula = _____

(4)

(b) Ethanol is formed by the fermentation of glucose.
A student carried out this fermentation reaction in a beaker using an aqueous solution of glucose at a temperature of 25 °C in the presence of yeast.

Write an equation for the reaction occurring during fermentation.

_____

(1)

(c) In industry, this fermentation reaction is carried out at 35 °C rather than 25 °C.

Suggest **one** advantage and **one** disadvantage for industry of carrying out the fermentation at this higher temperature.

Advantage _____

_____

Disadvantage _____

_____

(2)

(d) The method used by the student in part (b) would result in the ethanol being contaminated by ethanoic acid.

How does this contamination occur?

_____

_____

(1)

(e) Give **two** differences between the infrared spectrum of a carboxylic acid and that of an alcohol other than in their fingerprint regions.
Use **Table A** on the Data Sheet.

Difference 1 _____

_____

Difference 2 _____

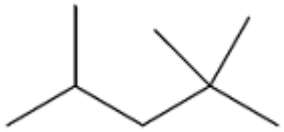
_____

(2)

(Total 10 marks)

Q17.

Isooctane (C_8H_{18}) is the common name for the branched-chain hydrocarbon that burns smoothly in car engines. The skeletal formula of isooctane is shown below.



(a) Give the IUPAC name for isooctane.

_____

(1)

(b) Deduce the number of peaks in the ^{13}C NMR spectrum of isooctane.

5 ⬭

6 ⬭

7 ⬭

8 ⬭

(1)

(c) Isooctane can be formed, together with propene and ethene, in a reaction in which one molecule of an alkane that contains 20 carbon atoms is cracked.

Using molecular formulas, write an equation for this reaction.

_____

(1)

(d) How do the products of the reaction in part (c) show that the reaction is an example of thermal cracking?

_____

(1)

(e) Deduce the number of monochloro isomers formed by isooctane.
Draw the structure of the monochloro isomer that exists as a pair of optical isomers.

Number of monochloro isomers

_____

Structure

(2)

(f) An isomer of isooctane reacts with chlorine to form only one monochloro compound.

Draw the **skeletal formula** of this monochloro compound.

(1)

(g) A sample of a monochlorooctane is obtained from a comet. The chlorine in the monochlorooctane contains the isotopes ^{35}Cl and ^{37}Cl in the ratio 1.5 : 1.0
Calculate the M_r of this monochlorooctane.

M_r = _____

(2)

(h) Isooctane reacts with an excess of chlorine to form a mixture of chlorinated compounds. One of these compounds contains 24.6% carbon and 2.56% hydrogen by mass. Calculate the molecular formula of this compound.

Molecular formula = _____

(3)

(Total 12 marks)

Q18.

A different kind of kiln is used to manufacture Portland cement. The main active minerals in Portland cement are called alite and belite.

(a) The table shows the composition of a compound found in alite that contains only the elements calcium, silicon and oxygen. Use these percentage by mass data to determine the empirical formula of this compound.

	Ca	**Si**	**O**
% by mass	52.67	12.30	To be calculated

_____

_____

_____

_____

_____

(3)

(b) A compound (Ca_2SiO_4) in belite reacts with water to produce $Ca_3Si_2O_4(OH)_6$ and $Ca(OH)_2$ Write an equation for this reaction.

_____

(1)

(c) Bags of Portland cement are labelled with hazard warnings.
Suggest an item of personal safety equipment, other than eye protection, that the warning label recommends.
Give a reason why this safety equipment is recommended.

Safety equipment _____

Reason _____

(2)

(Total 6 marks)

Q19.

An organic compound is found to contain 40.0% carbon, 6.7% hydrogen and 53.3% oxygen.

Which of the following compounds could this be?

A Ethanol ⬭

B Ethanoic acid ⬭

C Methanol ⬭

D Methanoic acid ⬭

(Total 1 mark)

Q20.

Compounds containing Cu^{2+}, OH^- and CO_3^{2-} ions are sometimes described as basic copper carbonates.

(a) Solid $Cu_2(OH)_2CO_3$ is added to an excess of dilute hydrochloric acid.
A solution of copper(II) chloride is formed, together with two other products.

(i) Write an equation for the reaction.

_____

(2)

(ii) Suggest **one** observation that could be made during the reaction.

_____

_____

(1)

(b) A 5.000 g sample of a different basic copper carbonate contains 0.348 g of carbon, 0.029 g of hydrogen and 1.858 g of oxygen.

(i) State what is meant by the term empirical formula.

_____

_____

(1)

(ii) Calculate the empirical formula of this basic copper carbonate.
Show your working.

_____

_____

_____

_____

_____

_____

_____

_____

(3)

(Total 7 marks)

Q21.

Compound **R** contains 61.0% carbon and 11.9% hydrogen by mass. The remainder is oxygen. The mass spectrum of **R** contains a molecular ion peak at *m*/*z* = 118.

(a) Use these data to show that the molecular formula of **R** is $C_6H_{14}O_2$.

_____

_____

_____

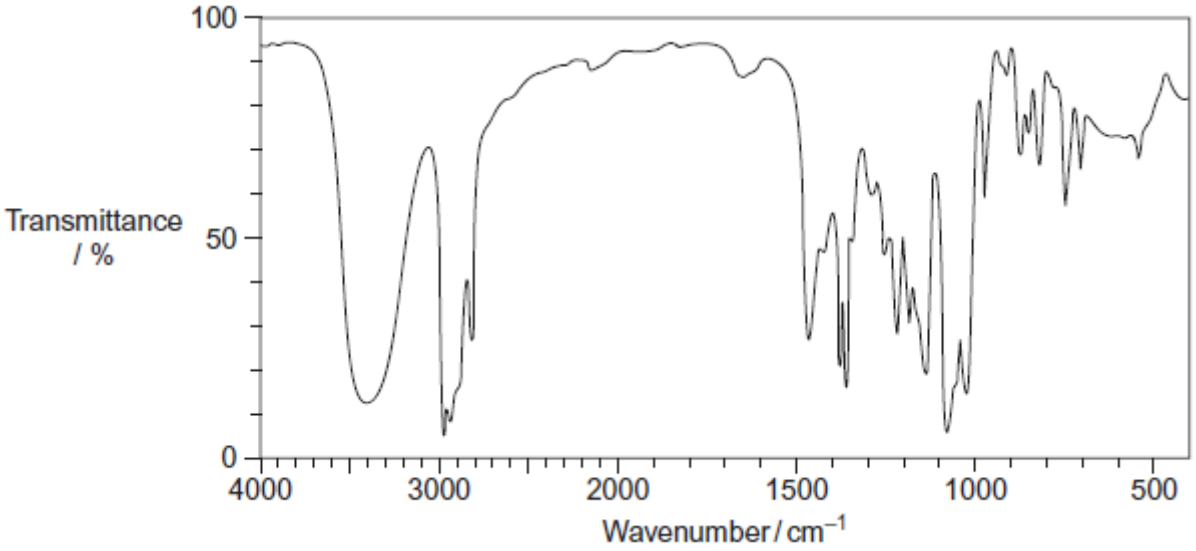
_____

_____

_____

(3)

(b) The infrared spectrum of **R** ($C_6H_{14}O_2$) is shown below.



The proton n.m.r. spectrum of **R** contains five peaks. The chemical shift values, integration ratios and splitting patterns of these peaks are given in the table.

Chemical shift/ppm	3.8	3.2	3.1	1.4	1.1
Integration ratio	2	3	1	2	6
Splitting patterns	triplet	singlet	singlet	triplet	singlet

When **R** is warmed with acidified potassium dichromate(VI) a green solution is formed.

Use **Table A** and **Table B** on the data sheet and all of the data provided in the question to deduce the structure of **R**.

In your answer, explain how you have used the data provided in the question.

(9)

(Total 12 marks)

Q22.

A sample of hydrated nickel sulfate ($NiSO_4.xH_2O$) with a mass of 2.287 g was heated to remove all water of crystallisation. The solid remaining had a mass of 1.344 g.

(a) Calculate the value of the integer x.
Show your working.

(4)

(b) Suggest how a student doing this experiment could check that all the water had been removed.

_____

_____

_____

_____

(2)

(Total 6 marks)

Q23.

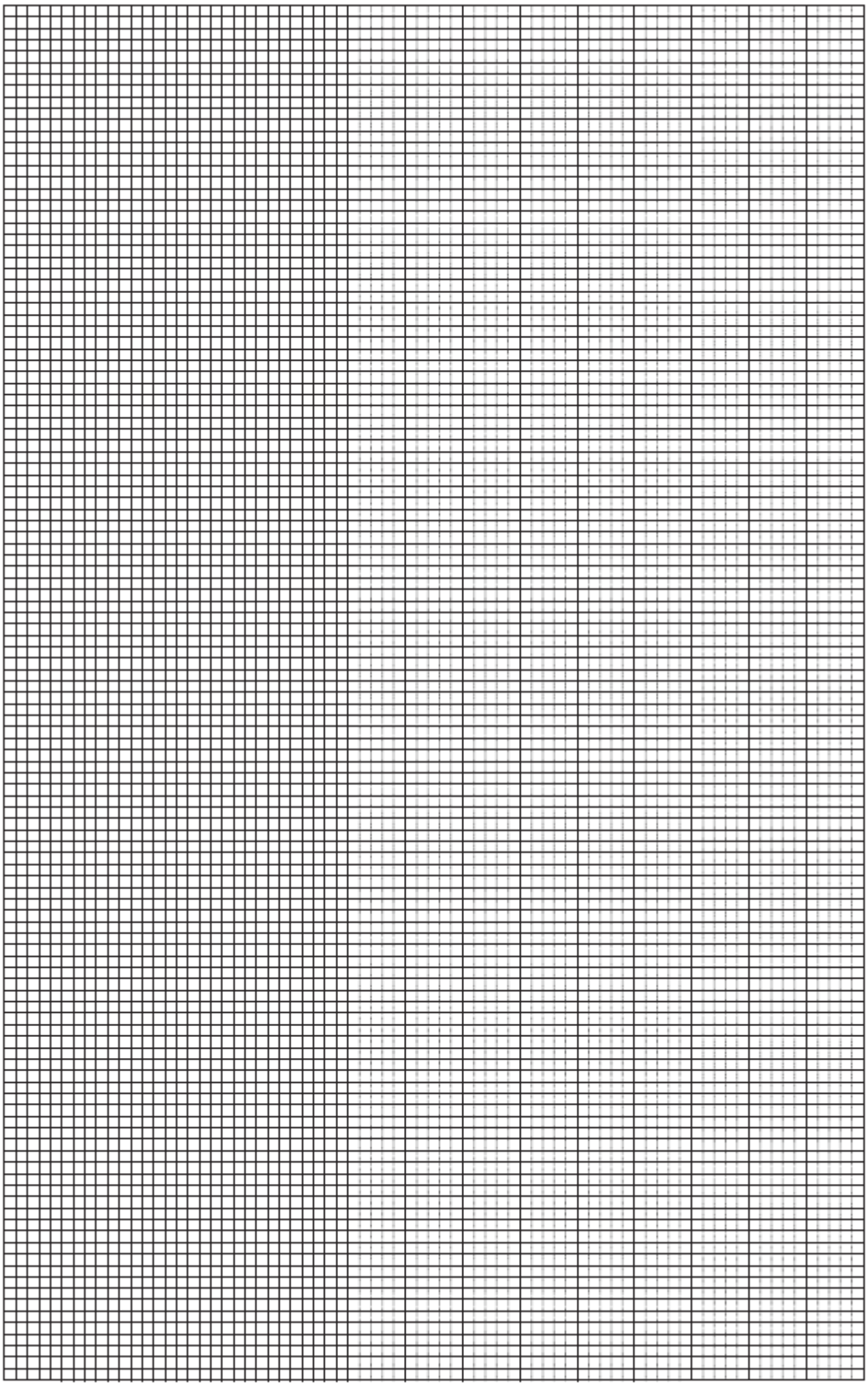
When boric acid (H_3BO_3) is applied as a coating on wood, it acts as a fire retardant by decreasing the rate of combustion.

Thermal decomposition of boric acid takes place in two stages.

In an experiment a sample of boric acid was heated in a crucible at 170 °C. The results of this experiment are given in the table.

Time of heating / minutes	Mass of crucible and contents / g
0	35.85
5	35.10
10	34.41
15	34.00
20	33.70
25	33.56
30	33.50
35	33.50

Plot a graph of the results from the table above to show the mass of the crucible and boric acid (*y*-axis) against time of heating on the grid.



(Total 4 marks)

Q24.

(a) Calcium phosphate reacts with aqueous nitric acid to produce phosphoric acid and calcium nitrate as shown in the equation.

$$Ca_3(PO_4)_2 + 6HNO_3 \longrightarrow 2H_3PO_4 + 3Ca(NO_3)_2$$

(i) A 7.26 g sample of calcium phosphate reacted completely when added to an excess of aqueous nitric acid to form 38.0 cm^3 of solution.

Calculate the concentration, in mol dm^{-3}, of phosphoric acid in this solution.
Give your answer to 3 significant figures.

(5)

(ii) Calculate the percentage atom economy for the formation of calcium nitrate in this reaction.
Give your answer to 1 decimal place.

(2)

(b) Write an equation to show the reaction between calcium hydroxide and phosphoric acid to produce calcium phosphate and water.

(1)

(c) Calcium dihydrogenphosphate can be represented by the formula $Ca(H_2PO_4)_x$ where x is an integer.
A 9.76 g sample of calcium dihydrogenphosphate contains 0.17 g of hydrogen, 2.59 g of phosphorus and 5.33 g of oxygen.

Calculate the empirical formula and hence the value of x.
Show your working.

(4)

(Total 12 marks)

Mark Scheme

Q16.

(a) Percentage of oxygen by mass = 100 – 40.9 – 4.5 = 54.6

1

	C	H	O
%			
Divide by A_r	$\frac{40.9}{12}$	$\frac{4.5}{1}$	$\frac{54.6}{16}$
	= 3.41	= 4.5	= 3.41

1

Divide by smallest =	$\frac{3.41}{3.41} = 1$	$\frac{4.5}{3.41} = 1.32$	$\frac{3.41}{3.41} = 1$
Nearest whole number ratio =	1 × 3	1.32 × 3	1 × 3
	= 3 : 3.96 : 3		
Nearest integer ratio =	3 :	4 :	3

1

Empirical formula $C_3H_4O_3$

Empirical formula mass = 88 = molecular formula mass

Therefore, molecular formula is same as the empirical formula - $C_3H_4O_3$

1

(b) $C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$

1

(c) Advantage – ethanol is produced at a faster rate

1

Disadvantage – more energy is used / required in the reaction

1

(d) Air gets in / oxidation occurs

1

(e) Alcohol OH absorption in different place (3230–3550 cm^{-1}) from acid OH absorption (2500–3000 cm^{-1})

1

The C=O in acids has an absorption at 1680–1750 cm^{-1}

1

[10]

Q17.

(a) 2,2,4-trimethylpentane

1

(b) 5

1

(c) $C_{20}H_{42} \longrightarrow C_8H_{18} + 2C_3H_6 + 3C_2H_4$

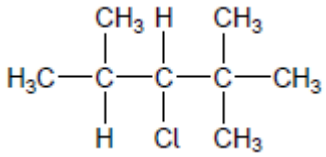
1

(d) Mainly alkenes formed

1

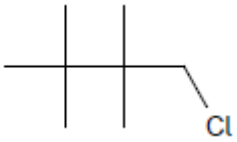
(e) 4 (monochloro isomers)

1



1

(f)



1

(g) $C_8H_{17}{}^{35}Cl = 96.0 + 17.0 + 35.0 = 148.0$
and $C_8H_{17}{}^{37}Cl = 96.0 + 17.0 + 37.0 = 150.0$
Both required

1

M_r of this $C_8H_{17}Cl$ $\frac{(1.5 \times 148.0)}{2.5} + \frac{(1.0 \times 150.0)}{2.5}$ = 148.8

1

(h) $\frac{24.6}{12} \quad \frac{2.56}{1} \quad \frac{72.8}{35.5}$ = 2.05 : 2.56 : 2.05

Simplest ratio = $\frac{2.05}{2.05} : \frac{2.56}{2.05} : \frac{2.05}{2.05}$

= 1 : 1.25 : 1

1

Whole number ratio (× 4) = 4 : 5 : 4

1

MF = $C_8H_{10}Cl_8$

1

[12]

Q18.

(a) Percentage of oxygen 35.03 **M1**

Values used throughout must be to a minimum of 2 s.f.

1

52.67 / 40.1 12.3 / 28.1 35.03 / 16 **M2**
OR
1.313 0.438 2.189
*If ratios are inverted lose **M2** and **M3***

1

Ca_3SiO_5 **M3**
*If correct formula only is given allow **M3** only.*

1

(b) $2\ Ca_2SiO_4 + 4\ H_2O \rightarrow Ca_3Si_2O_4(OH)_6 + Ca(OH)_2$
Accept multiples and fractions. Ignore state symbols.

1

(c) Gloves / Dust or face-mask
Ignore references to use of fume cupboard.

1

Cement is alkaline / caustic / corrosive / irritant
Accept 'Ca(OH)$_2$ formed is alkaline / caustic / corrosive / irritant'.

1

[6]

Q19.

B

[1]

Q20.

(a) (i) $H_2O + CO_2$ (as products in any equation)
Allow $H_2O + H_2CO_3$

1

$Cu_2(OH)_2CO_3 + 4HCl \rightarrow 2CuCl_2 + 3H_2O + CO_2$
Allow multiples
Ignore states

1

(ii) Bubbles or fizzing or effervescence
Or solid disappears
Or blue(-green) solution
Do not allow dissolves
Ignore CO_2 gas or gas evolved

1

(b) (i) Simplest (whole-number) ratio of atoms of each element in a compound
Allow atoms of Cu, H & O in this compound

1

(ii) Mass of copper = 2.765
Dividing masses by A_r

1

Cu	C	H	O
$\frac{2.765}{63.5}(=0.0435)$	$\frac{0.348}{12.0}(=0.029)$	$\frac{0.029}{1.0}(=0.029)$	$\frac{1.858}{16.0}(=0.116)$

1

Correct whole number ratio of integers
or
Cu:C:H:O
3:2:2:8
or
Correct empirical formula $Cu_3C_2H_2O_8$

Any order

Ignore $Cu_3(OH)_2(CO_3)_2$

1

[7]

Q21.

(a) Method 1

M1 %O = 27.1

$\frac{61.0}{12.0}$	$\frac{11.9}{1.0}$	$\frac{27.1}{16.0}$
= 5.08	= 11.9	= 1.69

M2 3 7 1

M3 C_3H_7O = 59 which is half of M_r so MF = 2EF

OR

Method 2

M1 61% of 118 = 72.0 and 11.9% of 118 = 14.0

M2 72 + 14 = 86 so oxygen = 32 out of 118

OR 27.1% of 118 = 32.0

M3

$\frac{72.0}{12.0}$	$\frac{14.0}{1.0}$	$\frac{32.0}{16.0}$
= 6	= 14	= 2

Method 3

Alternative using given molecular formula

M1 $C = \frac{12 \times 6}{118} \times 100 = 61.0\%$

M2 $H = \frac{14 \times 1}{118} \times 100 = 11.9\%$

M3 $O = \frac{16 \times 2}{118} \times 100 = 27.1\%$

3

(b) For this question, marks can be awarded either for a description of how the structure is derived or from the given structure itself. The maximum mark to be awarded is nine from the ten marks listed.

Marks fall into three sections:

- Infrared evidence : two marks are available for use of the infrared evidence, (M1 and M10)
- Chemical evidence: one mark is available for use of the chemical evidence (M2)
- N.m.r. evidence: six marks are available for use of the n.m.r. evidence (M3 – M8 inclusive)

plus one mark (M9) for a completely correct structure.

Suggested procedure for marking

First look at the infrared spectrum: marks M1 and M10 may be scored there or in the written answer.

Then look for use of the acidified potassium dichromate(VI) evidence, (M2).

Then look at the final structure: this may lead to the award of marks M3 to M9 as shown on the structures below.

Beware contradictions, e.g. using the chemical evidence they may state that **R** is a primary or secondary alcohol but then draw a tertiary alcohol. This will lose M2 but may score M3.

The written 'evidence' frequently simply contains extracts from the Table **B** on the Data Sheet and, if only this is given, is unlikely to score many marks.

Described

Or drawn

M1 Infared peak/absorbance at 3400 (cm^{-1}) = O-H alcohol
(reference to ir spectrum needed)

Note: please check the spectrum

If peak at 3000 (cm-1) is identified as acid then cannot score M1 (contradiction)

M10 **Either** no peak between 1680-1750 (cm^{-1}) so no C=O or not aldehyde/acid
OR peak at 1000-1300 (cm^{-1}) so C–O present

Apply list principle to IR analysis for M10

M2 (Acidified potassium dichromate(VI) turns green) so primary alcohol or secondary alcohol or not tertiary alcohol

Ignore aldehyde here

Lose M2 if just tertiary alcohol in structure

M3 δ = 3.1 singlet or integration = 1 is O-H

Award M3 if structure has 1 O-H group only (can be primary, secondary or tertiary)

Lose M3 if more than one OH group shown

M4 two triplets at 1.4 & 3.8 = $–CH_2–CH_2–$

Allow $–CH_2–CH_2–CH_2–$

M5 δ = 3.8 means CH_2 attached to O (in ether NOT ester)

Allow $O–CH_2–CH_2–CH_2–C$

δ = 1.4 means CH_2 attached to C (but not to C=O)

M6 δ = 1.1 (singlet) integration 6 = 2 × equivalent CH_3 on same C

$–C(CH_3)_2–$

M7 δ = 1.1 singlet so no H attached to $–C(CH_3)_2-$

$R–C(CH_3)_2–R$

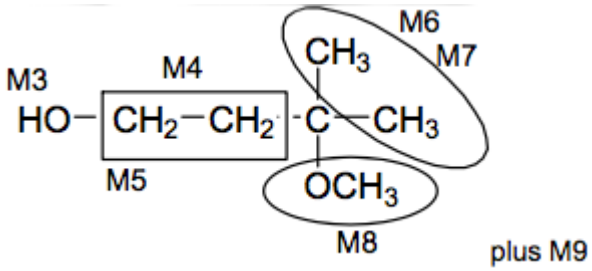
M8 δ = 3.2 singlet integration 3 = $-OCH_3$

$–OCH_3$

M9 For completely correct

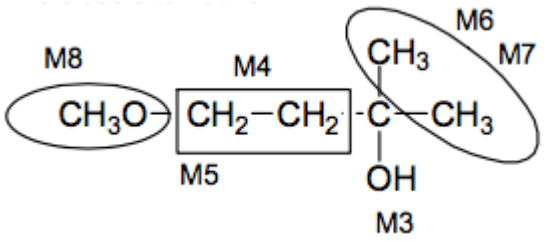
If no structure given then Max 8

R is



plus M9

This close alternative



would not score M9, but could score up to 8 marks

[12]

Q22.

(a) 0.943 g water (M1)

If Mr of $NiSO_4$ wrong, can allow M1 and M3 from method 1 i.e. max 2

$NiSO_4$ H_2O

$\frac{1.344}{154.8}$ (M2) $\frac{0.943}{18}$ (M3)

(8.68×10^{-3} 0.052)

1 6 or $x = \underline{6}$ (M4)

Allow Mr = 155

Allow other methods e.g.

M_r ($NiSO_4$) = 58.7 + 32.1 + 64.0 = 154.8

n($NiSO_4$) = $\frac{1.344}{154.8}$ = 0.008682 mol (M1)

M_r ($NiSO_4.xH_2O$) = $\frac{2.287}{0.008682}$ = (263.4) (M2)

so $18x$ = 263.4 − 154.8 = (108.6) (M3)

so x = $\frac{108.6}{18}$ = $\underline{6}$ (M4)

If using alternative method and Mr of $NiSO_4$ wrong, allow ecf to score M2 and M3 only i.e. max 2

4

(b) re-heat

Heat to constant mass = 2 marks

1

check that mass is unchanged

M2 dependent on M1

Allow as alternative:

M1: record an IR spectrum

M2: peak between 3230 and 3550 (cm^{-1})

1

[6]

Q23.

Mass of crucible and boric acid on the y−axis

Axes must be labelled but do not penalise lack of units (unless incorrect).

1

Suitable scale used

Plotted points must cover at least half the printed grid.(both directions).

1

All points plotted correctly

Allow + / − one small square.

1

Suitable line drawn

Good best−fit line based on their points (+ / − one small square).

Do not award if kinked, doubled or very thick line.

1

[4]

Q24.

(a) (i) M1 - M_r calcium phosphate = 310(.3)

If M_r wrong, lose M1 and M5.

1

M2 - Moles calcium phosphate = $\frac{7.26}{M1}$ (= 0.0234)

0.0234 moles can score M1 and M2.

If M_r incorrect, can score M2 for $\frac{7.26}{M1}$.

Allow M2 and / or M3 to 2 significant figures here but will lose M5 if answer not 1.23.

1

M3 - Moles phosphoric acid = 2 × 0.0234 = 0.0468

Allow student's M2 × 2. If not multiplied by 2 then lose M3 and M5.

1

M4 - Vol phosphoric acid = 0.038(0) dm^3

If not 0.038(0) dm^3 then lose M4 and M5.

1

Conc phosphoric acid = $\frac{0.0468}{0.038(0)}$

M5 = 1.23 (mol dm^{-3})

This answer only – unless arithmetic or transcription error that has been penalised by 1 mark.

Allow no units but incorrect units loses M5.

1

(ii) $\frac{492.3}{688.3} \times 100$ **OR** $\frac{492}{688} \times 100$

1 mark for both M_r correctly placed.

= 71.5%

2

(b) $3Ca(OH)_2 + 2H_3PO_4 \longrightarrow Ca_3(PO_4)_2 + 6H_2O$

Allow multiples.

1

(c)

Ca	H	P	O
1.67	0.17	2.59	5.33
40.1	1	31	16
= 0.042	0.17	0.084	0.333
1	4	2	8

If x = 2 with no working, allow M4 only.

Ca = 1.67 g (M1).

1

Mark for dividing by correct A_r in Ca and P (M2).
If M1 incorrect can only score M2.

1

Correct ratio (M3).

1

$CaH_4P_2O_8$ **OR** $Ca(H_2PO_4)_2$ **OR** x = 2

Value of x or correct formula (M4).

1

Alternative

Ca H_2PO_4

Ca = 1.67 g (M1).

$\frac{1.67}{40.1}$ $\frac{8.09}{97.0}$

Mark for dividing by correct A_r / M_r in Ca and H_2PO_4 (M2).
If M1 incorrect can only score M2.

$= \frac{0.042}{1}$ $\frac{0.083}{2}$

Correct ratio (M3).

$CaH_4P_2O_8$ **OR** $Ca(H_2PO_4)_2$ **OR** x = 2

Value of x or correct formula (M4).

[12]